PERFORMANCES OF A SPARK IGNITION (SI) ENGINE FUELLED WITH LIQUEFIED PETROLEUM GAS (LPG) USING LIQUID SEQUENTIAL INJECTION (LSI) TECHNIQUE

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To my beloved parents, friend,

for their endless love, support and tolerance

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ABSTRACT

The increment of fuel cost and environmental pollutions from transportation sector has created interest on alternative fuels particularly in spark ignition (SI) engines. One of the seen potential of alternative fuel is Liquefied Petroleum Gas (LPG). LPG has a research octane number higher than gasoline and low carbon to hydrogen ratio content, thus the LPG has the potential to give more power in SI engines and to reduce exhaust emissions. An experimental work was conducted on a 1.6 Liters, 4-cylinder engine from a Proton Gen 2 (S4PH), equipped with gasoline Multi Point Port Injection (MPI) system. The engine was retrofitted with LPG Liquid Sequential Injection (LSI) and a piggy-back system emulated the stock Electronic Control Unit (ECU). The engine was tested in steady state conditions, which are based on engine speed from 1500rpm to 4000rpm with increment of 500rpm. The Throttle Position (TP) was varied at four different levels that were 25%, 50%, 75% and 100% for every engine speed tested. The findings from the experiment showed that the liquid phase LPG increased brake power (BP) and brake torque (BT) in the range of 3% to 7%. The brake specific fuel consumption (BSFC) of LPG at low engine speed (1500rpm to 2500rpm) was reduced in the range from 21% to 52%. Meanwhile, at higher engine speed (3000rpm to 4000rpm) the LPG BSFC increased in average between of 3% to 57%. The carbon monoxide (CO) exhaust emission was reduced in the range of 2% to 19% when using LPG. The carbon dioxide (CO_2) is also lower than gasoline in average between 9% and 18%. The hydrocarbon (HC) emission from LPG was increased in the range of 40% to 70%, and concentration of NO_x emission was increased in average of 60% in comparison with gasoline. As a conclusion, the LPG LSI system used in S.I engine is more effective than gasoline at low engine speed condition due to low fuel consumption and emission.

ABSTRAK

Peningkatan kos bahan api dan pencemaran alam sekitar yang terhasil daripada sektor pengangkutan telah menarik minat terhadap penggunaan bahan api alternatif yang digunakan pada sistem enjin pencucuhan percikan api (SI). Salah satu potensi yang di lihat sebagai bahan api alternatif ialah gas petroleum cecair (LPG). LPG mempunyai nombor penyelidikan oktana (RON) yang tinggi disamping kandungan nisbah karbon yang rendah dibandingkan dengan hidrogen. Oleh itu LPG berpotensi untuk memberi kuasa yang lebih pada enjin SI dan mengurangkan pencemaran pelepasan asap ekzos. Pada kajian ini, eksperimen dijalankan pada enjin 1.6Liter, 4-silinder dari Proton Gen 2 (S4PH) dan sistem penghantaran bahan api dilengkapi oleh sistem multi suntikan (MPI). Enjin ini telah dimodifikasi dengan suntikan turutan cecair (LSI) LPG dan sistem unit kawalan eletronik (ECU) yang asal pula telah disambungkan kepada sistem LSI tersebut. Enjin telah ditetapkan kepada mod keadaan kekal, di mana kelajuan putaran enjin bermula dari 1500rpm hingga 4000rpm dengan peningkatan kelajuan putaran enjin sebanyak 50rppm. Terdapat empat perbezaan kedudukan posisi injap pendikit (TP) iaitu 25%, 50%, 75% dan 100% untuk setiap ujikaji mod kekal dijalankan. Hasil dapatan kajian menunjukkan pengunaan LPG pada fasa cecair telah meningkatkan kuasa brek (BP) dan tork brek (BT) dalam lingkungan 3%-7%. Brek penggunaan bahan api khusus (BSFC) bagi LPG telah berkurang sebanyak 21%-52% pada kelajuan rendah putaran enjin (1500ppm-2500ppm). Manakala BSFC pada kelajuan tinggi putaran enjin (3000rpm-4000rpm) menunjukkan peningkatan 3%-57%. Pencemaran CO telah berkurang sebanyak 2%-19% dan CO_2 juga berkurang dalam purata 9% dan18% apabila LPG digunakan. Pencemaran HC mencatatkan peningkatan sebanyak 40%-70% dan NO_x juga meningkat kepada 60% apabila dibandingkan dengan gasoline. Kesimpulannya, pengunaan sistem LPG LSI pada enjin S.I adalah lebih efektif berbanding gasoline jika digunakan pada kelajuan rendah putaran enjin.

CONTENTS

LIST OF TABLES

LIST OF FIGURE

LIST OF THE SYMBOLS AND ABBREVIATIONS

AFR	-	Air/fuel Ratio
BP	-	Brake Power
BT	-	Brake Torque
BDC	-	Bottom Dead Center
BOB	-	Bubbling on Board
BSFC	-	Brake Specific Fuel Consumption
BTDC	-	Before Top Dead Center
CEN	-	European Committee for Standardization
CI	-	Compression Ignition
CNG	-	Compress Natural Gas
CO	-	Carbon Monoxide
CO_2	-	Carbon Dioxide
C_3H_8	-	Propane
C_4H_{10}	-	Butane
DI	-	Direct Injection
ECU	-	Electronic Control Unit
EDU	-	Engine Driver Unit
EGR	-	Exhaust Gas Recirculation
EIA	-	Energy Information Administration
FSS	-	Fast Fill Station
GDI	-	Gasoline Direct Injection
GGE	-	Gasoline Gallon Equivalent
HC	-	Hydrocarbon
HCCI	-	Homogeneous Charge Compression Ignition

HP	-	Horsepower
H_2O	-	Water Molecule
H_2S	-	Hydrogen sulfide
ICE	-	Internal Combustion Engine
LPG	-	Liquefied Petroleum Gas
LSI	-	Liquid Sequential Injection
MPI	-	Multi Point Port Injection
MSDS	-	Materials Safety Data Sheet
NA	-	Naturally Aspirated
NDIR	-	Non-disperse infrared
NO_x	-	Oxide of Nitrogen
OBD	-	On-board Diagnostic
OEM	-	Original Equipment Manufacturer
O_2	-	Oxygen
PFI-G	-	Phase Port Injection - Gaseous
RON	-	Research Octane Number
rpm	-	Rotation-Per-Minutes
SAE	-	Society Automotive Engineering
SI	-	Spark Ignition
TBI	-	Throttle Body Injection
TBI-G	-	Throttle Body Injection - Gas
TDC	-	Top Dead Center
TP	-	Throttle Position

LIST OF APPENDIX

CHAPTER 1

INTRODUCTION

1.1 Background of Study

This ever-increasing consumption of fuel has led the world to face the twin challenge; fuel scarcity and environment deterioration. The transportation sector has experienced steady growth in the past 30 years, which almost entirely relies on fossil fuels, oil in particular. This oil demand is projected to be increased around 60% of the growth and expected to increase further in the future, where the current reserves-to-production ratios are projected to stay in remaining 40 years (Leung, 2011). The numbers of demand is directly proportional to the rate of production, which will affected the draining current fossil fuel reserve levels at a faster rate. This has resulted in fluctuating oil prices and supply disruptions. In form of the deterioration an environmental issues, the transportation sector had also contributed to a huge and growing share of emissions that affects global climate; namely Green House Gases (GHG) emissions. In additional, the GHG emissions from the transportation sector were responsible for about 23% and keep increasing from year to year (Khan *et al*., 2009). To overcome these limitations, the use of an alternative fuel is the best option to be considered. Some of the promising alternatives are Liquefied Petroleum Gas (LPG), Compressed Natural Gas (CNG), bio-fuel, Hydrogen and others.

1.1.1 Demands of Fuel

Figure 1.1 shows the demands of conventional fuel increase every year. This is because the automotive and transportation industry has grown tremendously worldwide. According to the Energy Information Administration (EIA, 2016), from 2010 until 2016 demands of a gasoline increased in the range of 30% to 40%. Meanwhile, the demands of Liquefied Petroleum Gas (LPG) are drastic decrease in the range 5% to 10% in every year. To avoid the demand and supply to become unstable, the introduction of alternative fuel technology for consumers may be an answer. Alternative fuel such as Liquefied Petroleum Gas (LPG), Compress Natural Gas (CNG), Biofuel, Hydrogen, Fuel cell, Electric vehicle, methanol and ethanol need to be highlighted, as the societal understanding how important alternative fuel. Consequently, introduce the alternative fuel will be stable the demands of fuel for spark ignition (SI) and Compression Ignition (CI) on the future.

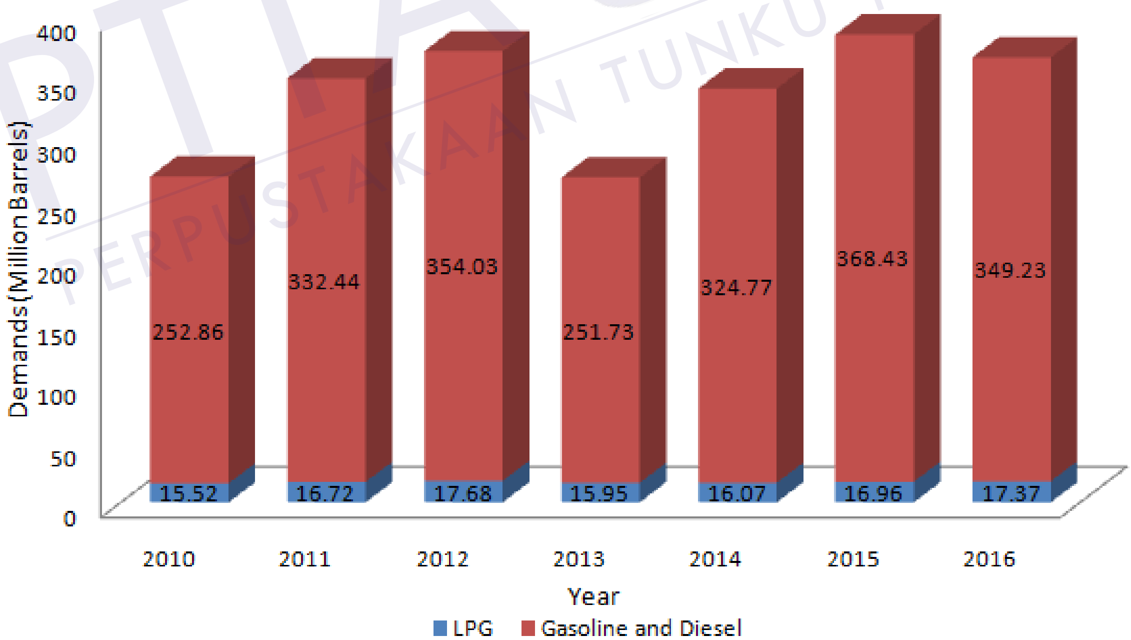

Figure 1.1: Total world demands of conventional fuel (reproduced from EIA, 2016)

1.1.2 Asian Fuel Price

Generally, the increasing demand of fossil fuel such as gasoline and diesel with respect to fuel supply has created economy turmoil particularly in transportation sector. The fluctuation of current fuel price depends on the demand of fuel in world wide. Figure 1.2 shows the trend of fuel price from 2010 to 2016. In sum, the fuel price increased from 2010 to 2011. The price for gasoline started at USD 2.75 to USD 3.48 per gasoline gallon equivalent (GGE). Thus, fuel price for diesel increased from USD 2.67 to USD 3.42 per GGE, and for LPG increased from USD 4.02 to USD 4.28 per GGE. On 2012 until 2014, the gasoline shows a fluctuated trend which started from USD 3.65, USD 3.50 and USD 3.51 per GGE. Diesel fuel price was decrease from USD 3.56, USD 3.54 to USD 3.49 per GGE. The price of LPG declined steadily from USD 3.86 to USD 3.83 and increased to USD 4.34 per GGE. In 2015 to 2016, the fuel price for gasoline has dropped from USD 2.47 to USD 2.10 per GGE. Meanwhile, diesel was dropped from USD 2.64 to USD 2.03 per GGE and LPG fuel price has decreased from USD 4.00 to USD 3.83.

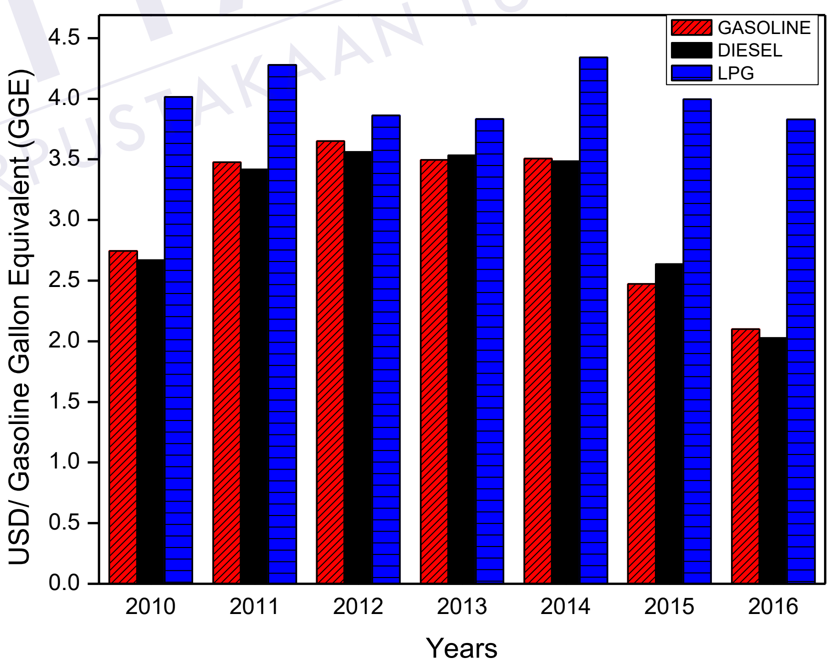

Figure 1.2: Price of fossil fuel from 2010 to 2016 (reproduced from EIA, 2016)

Due to an increased demand and fluctuated fuel price in the world, the Asian fuel prices also effected, especially in Malaysia. Until March 6, 2017, the fuel price was trading at USD 0.52 per liters for gasoline and USD 0.5 for the diesel as shown in Figure 1.3. The fuel price of gasoline is lower than other country in Asia and the diesel fuel is the second lower price after Brunei due to the government subsidy. The subsidy is invalid for the industrial and commercial purpose. Consequently, this has created a burden on economy development, especially in the transportation sector, where companies need to bear the higher costs of operating due to fluctuation in fuel price.

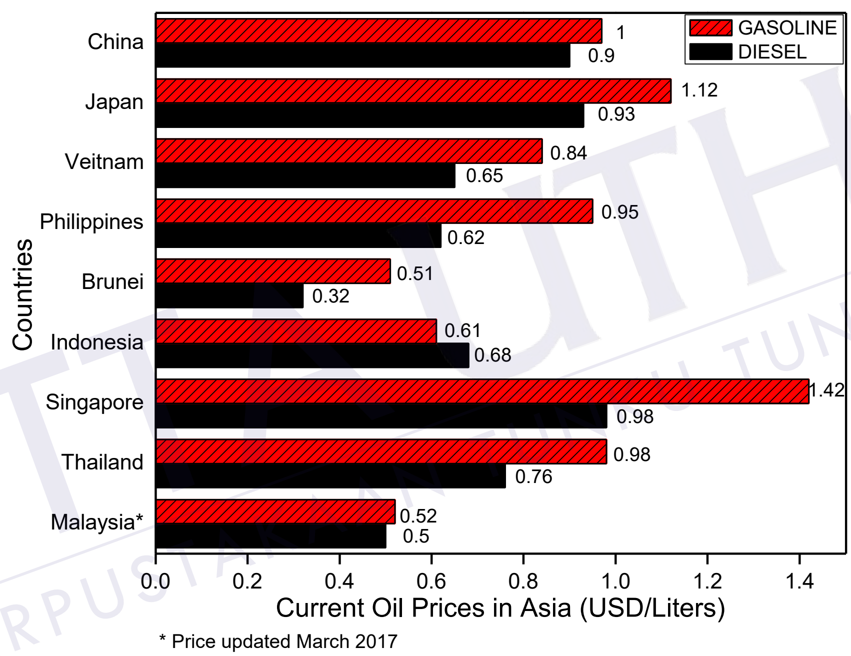

Figure 1.3: Fuel price in Asia (reproduced from MyTravelCost, 2017)

1.1.3 Emission from Vehicle in the Transport Sector

Until 2014, the total number of registered road vehicle in Malaysia increased in the range of 4% to 5% annually. Figure 1.4 shows the total of transport registered between 2010 and 2014. The figure was reproduced from the Road Trasport Department of Malaysia., (2016). The trend indicated a sharp growth in the use of motorcycle, from 2011 to 2014 the motorcyclists was recorded from 9.442 million to 11.629 million. The trend also same with the motorcar, the number of registered vehicle is increased from

9.115 million to 11.028 million annually, followed by good vehicle, bus and taxi. The increment of transportation industries and low price of vehicles have increased the number of vehicles registered in Malaysia especially in the urban areas, has led to the increment of environmental contamination.

The increasing the number of vehicles, contribute to the increasing overall carbon dioxide (CO_2) concentration emission in Malaysia. Figure 1.5 shows the trend of the total CO_2 emission from consumption of gasoline and diesel fuel. According to the Natural Resources and Environment, (2014) the figure shows the increasing of CO_2 emission from 1990 to 2010 annually. The CO_2 emission from 1990 to 1995 was recorded at an average of 102.6 million metric tons, meanwhile at 1995 to 2000 CO_2 emission was increased by 116 million metric tons. Following from 2000 to 2005 the increasing of total emission was at 127.4 million metric tons. Lastly, from 2005 to 2010 the CO_2 emission reached at 130 million metric tons. The increase of CO_2 is a very critical problem because it affects the greenhouse gas and global warming. As an effort to reduce the CO_2 emission in Malaysia, alternative fuel, namely LPG in liquid phase can be introduced. In addition, according to Myung *et al*., (2012) LPG produced more power, less pollutant emitted and the demands still low compared to conventional fuel.

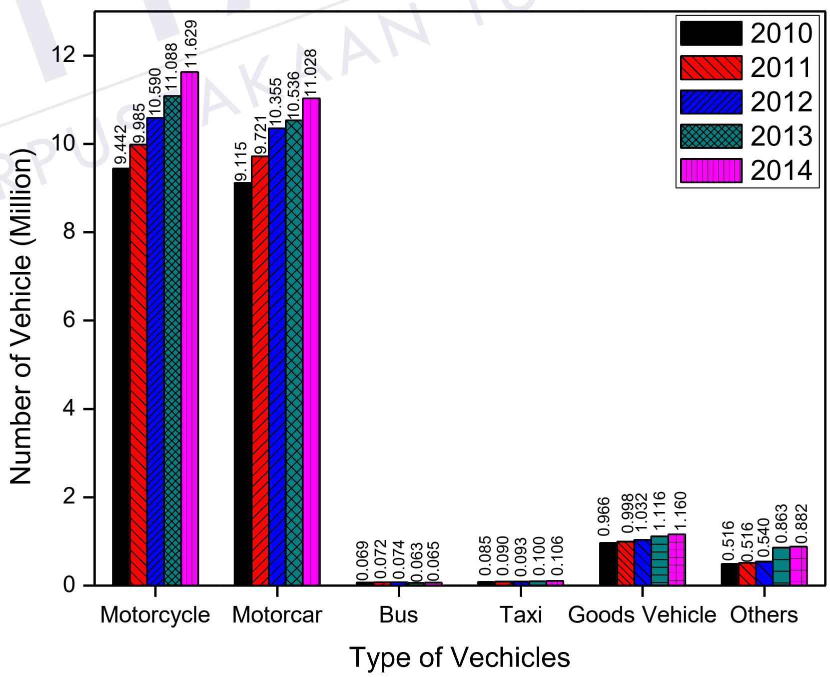

Figure 1.4: Total registered vehicle in Malaysia from 2010 to 2014 according to type (reproduced from Road Trasport Department of Malaysia, 2016)

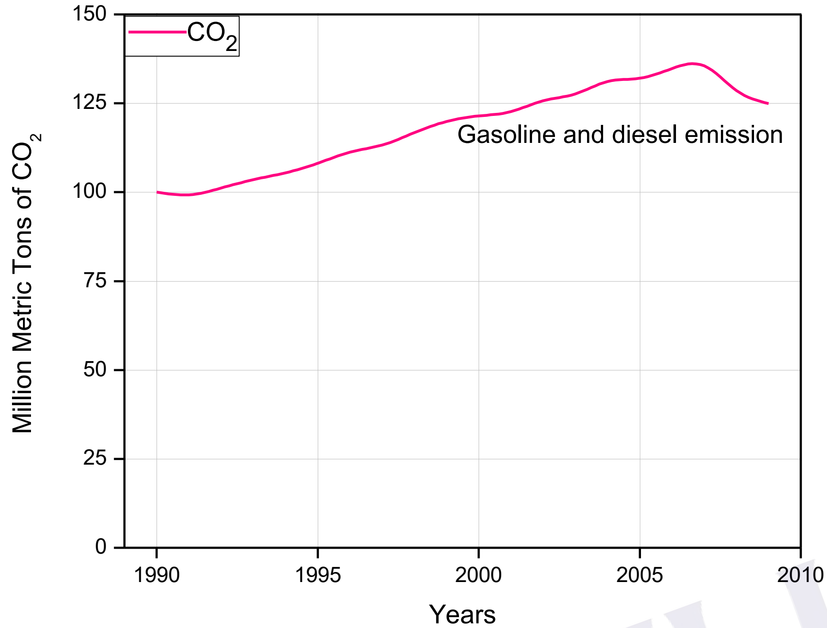

Figure 1.5: Malaysia's total CO_2 emission from consumption of conventional fuel (reproduced from Natural Resources and Environment, 2014)

1.2 Problem Statement

The CO_2 pollution issue was elevated in this country, which caused from transportation sector that has increased at an average of 118.6 million metric tons in every five years. In addition, world crude oil demands and supplies are dwindling, this cause the cost of gasoline becoming increasingly expensive. In this research, several steps were being chosen wisely to resolve this problem, the vehicle was retrofitted with LPG liquid phase system as a bi-fuel system. This is because the liquid phase LPG produced low emission and lower fuel consumption than gasoline. The brake power (BP) and brake torque (BT) are comparable with gasoline, but the modification leads to the discovery of several technical problems was studies by Kang *et al.*, (2001), Sobiesiak *et al.*, (2003), Gumus, (2011), Myung *et al.*,(2014) and Farrugia *et al.*, (2014).

According to Kang *et al.*,(2001) in year 2000 more than 6 million uses LPG on the vehicle in Korea. The LPG vehicle received a warm welcome in automotive industry. The LPG conversion systems can be divided into five generations, where the first to fourth generation used gas phase for the fuel delivery system, while the latest technology system uses LPG in liquid phase. Based on the latest technologies of the LPG conversion system; the Liquid Sequential Injection (LSI) technique offers various advantages in comparison with the previous generation system. This implementation of retrofitted LPG-LSI in SI engine is still limited and has substantial research gaps. However, the implementing barriers need to be solved are:-

i. Retrofitting LPG LSI system for S.I engine
ii. The methodologies of fuel refuelling for the system
iii. The unknown characteristics of LPG LSI system in local vehicle in terms of for S.I. engine; engine performances and exhaust gas emissions
iv. The trade-off fuel consumption analysis for both gasoline and retrofitted LPG-LSI engine

Therefore, it is desired to have a spark ignition (SI) engine from local vehicle to install LPG LSI system is functioning in bi-fuel system for running the both of fuel in experiments. By installing an LPG LSI system in the local vehicle, it may open up alternative solutions to solve the current issue.

1.3 Objectives

The objectives of this research are:

a) To identify the influence of liquid sequential injection (LSI) system liquified petroleum gas (LPG) system of a Spark-ignition (SI) engine
b) To establish an LPG refueling system for an LPG tank designed for LSI application
c) To analyze the engine performance and exhaust emission of gasoline fuel and LPG

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